OPEN-PIT COPPER MINING METHODS AND COSTS AT THE BAGDAD MINE, BAGDAD COPPER CORP., YAVAPAI COUNTY, ARIZ.

By W. R. Hardwick and E. L. Jones III

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OPEN-PIT COPPER MINING METHODS AND COSTS AT THE BAGDAD MINE, BAGDAD COPPER CORP., YAVAPAI COUNTY, ARIZ.[1]

by

W. R. Hardwick[2] and E. L. Jones III[3]

SUMMARY

This information circular describes open-pit mining methods and practices of the Bagdad Copper Corp., Yavapai County, Ariz. It is one of a series being prepared by the Federal Bureau of Mines on mining methods, practices, and costs in various mining districts of the United States.

A brief history of the Eureka district and of early developments at the Bagdad mine is given, and the ore deposit is described with particular emphasis on those characteristics (physical, economic, or engineering) that affected the choice of mining methods. Prospecting, exploration, and sampling and estimating the tonnage and grade are outlined. Development of the open-pit mine is shown. Mining methods, including breaking ground, primary drilling and blasting, secondary drilling and blasting, loading, transportation, engineering, and operating control, are described. A brief summary of mining equipment is given. Percentage of extraction, production rate, mine drainage and water supply, wage, contract, and bonus systems, safety and fire prevention, and the processing plant also are described. The last section gives a breakdown of such costs as are available for publication.

INTRODUCTION

In recent years the Bagdad mine has been converted from an underground to an open-pit operation. The Bagdad ore was mined underground by the block-caving method. Then for a time a glory-hole system was used, and the ore was broken in benches on the surface, bulldozed into raises, trammed to the shaft, and hoisted to the mill on the surface. Finally the open-pit method of mining was adopted.

The mine was visited in June 1957, and information for this report was obtained at that time.

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[1] Work on manuscript completed June 1958.
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ACKNOWLEDGMENTS

Acknowledgment is made to the executives and staff of the Bagdad Copper Corp. for permission to publish this report. Special acknowledgment is due George W. Colville, general manager of the Bagdad mine.

Information from published articles has been acknowledged in footnotes to the text. Information also was obtained from annual reports to the stockholders of the Bagdad Copper Corp. The maps and plans used in this report were furnished by the company, unless otherwise stated.

HISTORY OF THE DISTRICT

The Bagdad mine (fig. 1) is in Yavapai County, Ariz., on Copper Creek, a small tributary of Boulder Creek; it is in sec. 4, T. 14 N., R. 9 W., Gila and Salt River base meridian, at an altitude of about 3,200 feet (fig. 2). The district is known as the Eureka mining district, and the Bagdad mine is reached by driving 27 miles on a paved road from Hillside, Ariz., a station on the Ashfork-Phoenix branch of the Santa Fe Railway.

The Bagdad claims were discovered in 1886 and patented in 1889 by John Lawler. Early production in the district was from gold-silver-lead fissure veins, however, and the first copper was not produced until after 1906. Several unsuccessful attempts to mine copper ore were made by other companies before the Bagdad Copper Corp. acquired the property in 1927 and explored the ore body by churn-drill holes.

In 1929 pilot-plant operation to test the ore was initiated, and in 1935 mining was begun on a small scale to test the application of the block-caving method to the ore body. In 1943 a 2,500-ton mill was completed, and mining 2,500 tons per day by the block-caving method was attempted seriously. Enough ore to supply the mill at capacity was not obtained from the caving operation. The ore body was thin, and a high rate of development footage was required. The ore was hard and broke coarsely, and dilution was high.

To increase production, some ore was mined by the glory-hole method. This method was used where capping was thin and waste could be stripped above the ore. Finally, the mining method was changed, and the open-pit method with truck haulage was adopted (fig. 3).

After conversion to open-pit mining, it became evident that costs could be reduced if plant capacity were increased. First, it was necessary to prove enough ore to justify the expansion program. The original 40,480 feet of churn-drill hole did not suffice; and, beginning in 1946, 54,000 feet of diamond-drill hole was completed and sampled. This drilling discovered enough additional ore to justify expanding the mine operation. The concentrating plant was improved by adding equipment and improving the flowsheet until in 1957 the capacity was 5,000 tons per day. Production by open-pit mine is listed in table 1.

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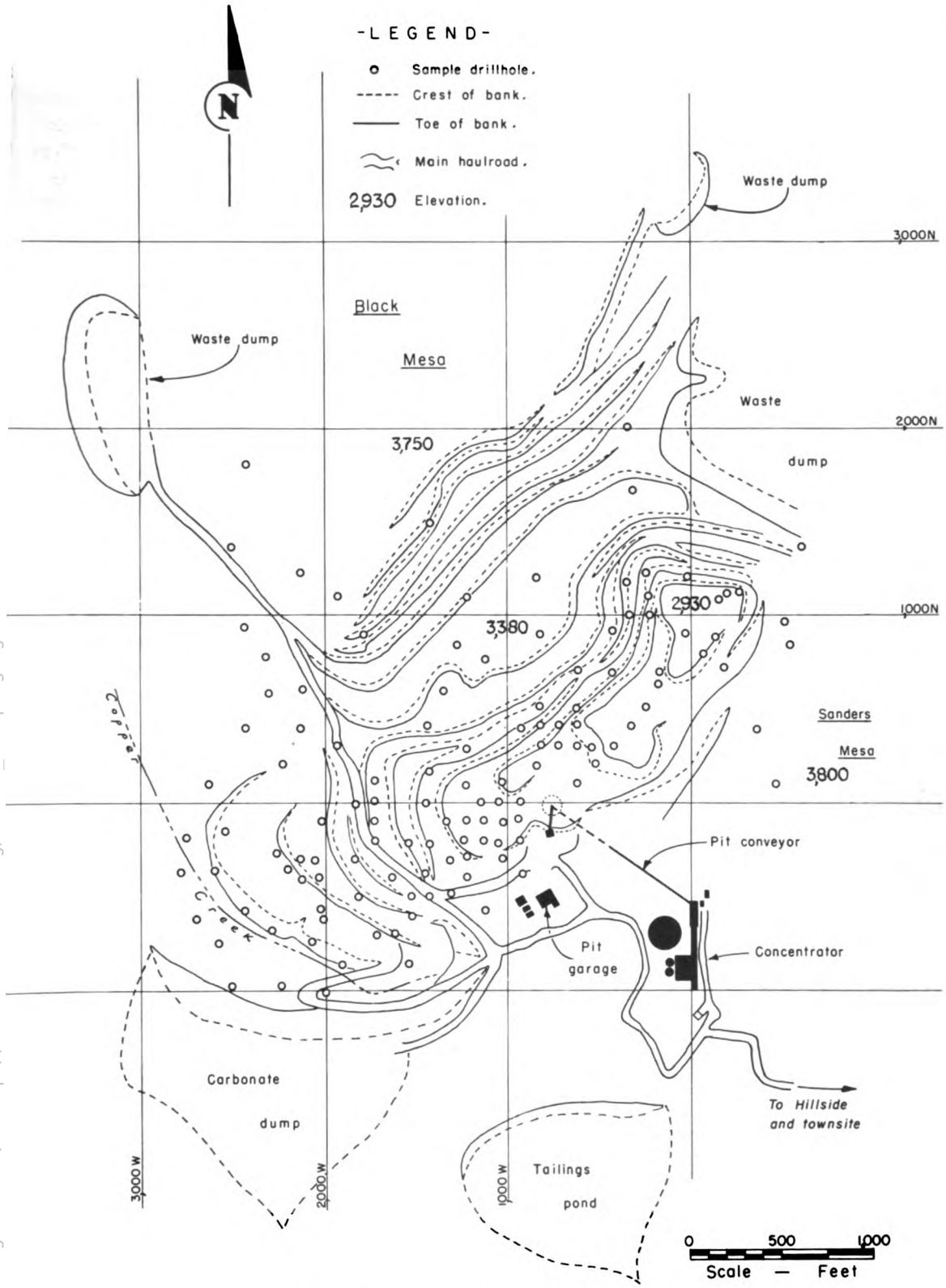

FIGURE 3. - Sketch Map, Bagdad Open Pit.

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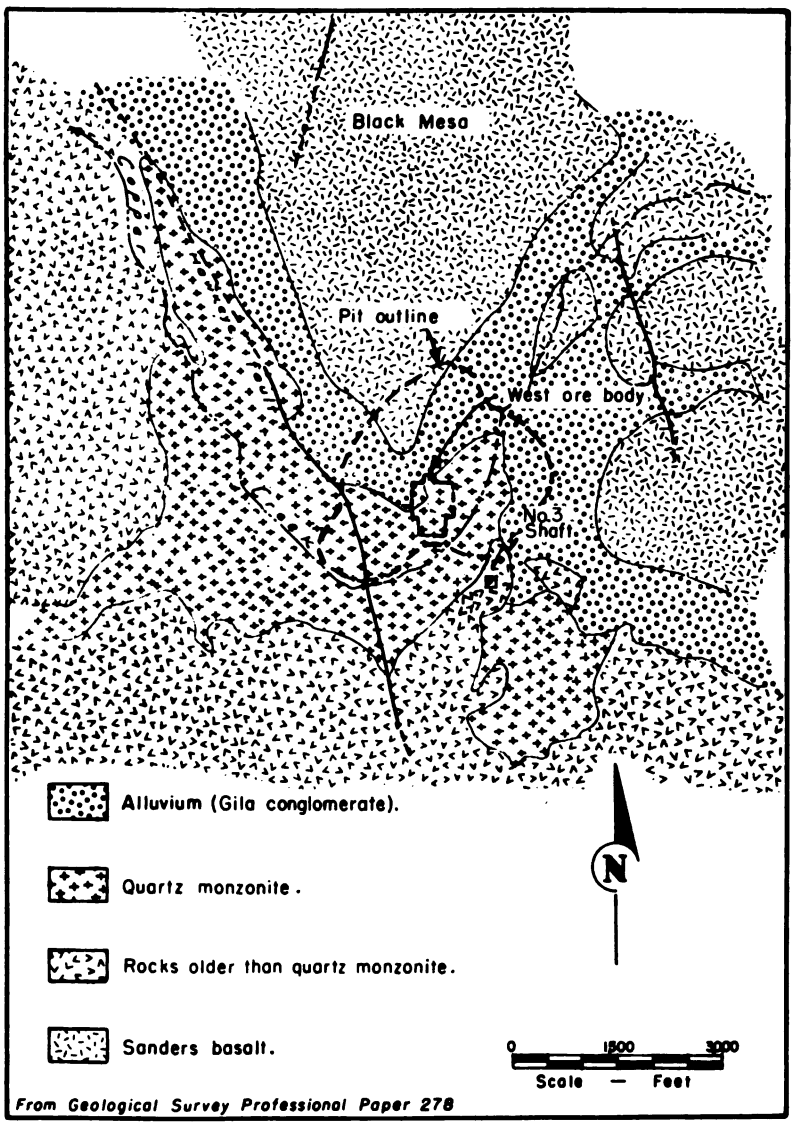

FIGURE 4. - Surface Geology, Bagdad Mine.

by oxidation of the sulfides. The older rocks surrounding the quartz monzonite have been cut by many dikes, which vary in age and composition. A few short, narrow dikes, 1 to 2 feet wide, occur in the quartz monzonite.

The northwest-trending Hawkeye fault cuts through the quartz monzonite and the ore body (fig. 5). According to Anderson, Scholz, and Strobell,4/ this fault dips 70° to 80° in an easterly direction and is a normal fault. The chalcocite ore body is present on the dropped hanging-wall block but is absent on the footwall side. Numerous minor fractures cut the quartz monzonite in the vicinity of the ore body. The primary ore minerals are pyrite, chalcopyrite, and molybdenite. The minerals generally are scattered as grains through the monzonite but in places occur in veinlets of quartz. Some galena, sphalerite, and barite are found in the monzonite.

Sometime after the ore body had been formed, the covering rocks and top part of the quartz monzonite were eroded. The pyrite and chalcopyrite were oxidized, and much of the copper was carried down and deposited as a blanket of chalcocite ore, thus leaving a leached and oxidized zone above as much as 350 feet thick. The oxidized rock, which must be removed before the underlying sulfide ore can be mined by the open-pit method, contains about 0.435 percent copper. The high-grade chalcocite zone averages 125 feet in thickness and dips 10° to 15° NE. The low-grade

4/ Anderson, C. A., Scholz, E. A., and Strobell, J. D., Jr., Geology and Ore Deposits of the Bagdad Area, Yavapai County, Ariz.: Geol. Survey Prof. Paper 278, 1956, 103 pp.

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sulfide ore that will be mined by the open-pit method is 350 feet thick and extends downward from an elevation of 3,230 feet.

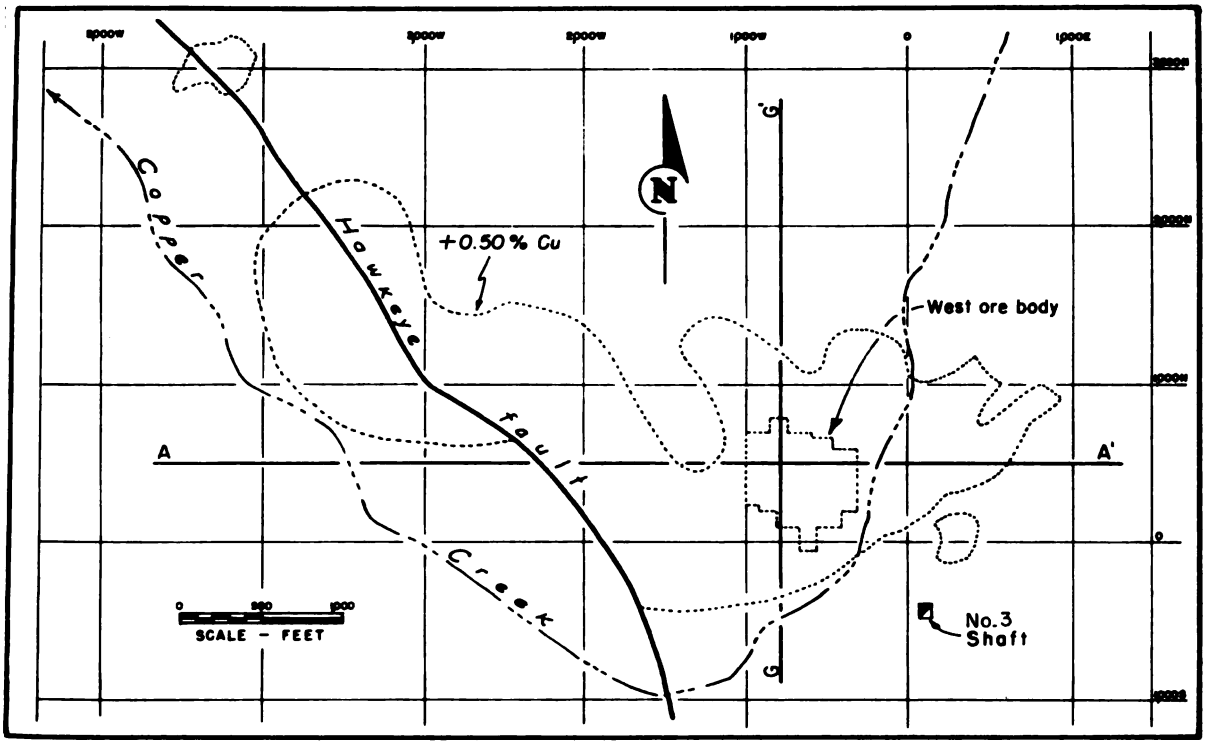

FIGURE 5. - Outline of Sulfide Ore Body.

After this period of erosion and leaching the whole area was covered with Gila conglomerate(?) to a depth of 200 to 250 feet; and the Gila conglomerate was covered with a bed of tuff 25 to 30 feet thick and a bed of basalt 50 to 75 feet thick (fig. 6). During the present erosion cycle, Copper Creek cut a channel through these covering beds and removed part of the leached monzonite. Thus the ore body is almost exposed on the surface along Copper Creek but is capped by several hundred feet of leached capping, Gila conglomerate, tuff, and basalt in other places.

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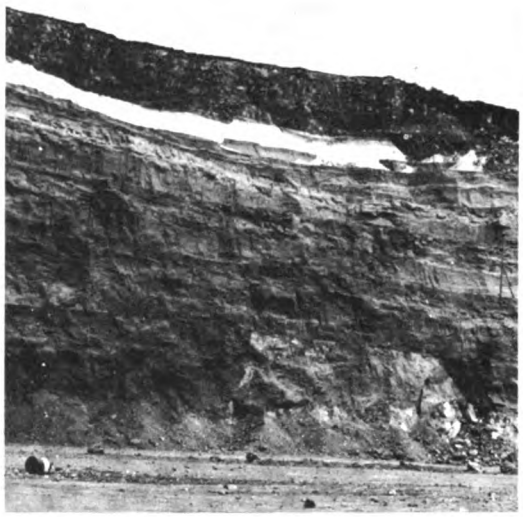

FIGURE 6. - Waste Banks Above 3,380-Foot Level.

The topography is moderately rugged; between Hillside and the mine it is such that the cost of building a railroad is prohibitive. The elevation of the surface over the ore body ranges from 3,250 feet in the bottom of Copper Creek to 3,750 feet on the point of Black Mesa that projects out over the ore body. There are no permanent streams near the mine, but water is available in the gravels along Boulder Creek, 7-1/2 miles northwest of the mine. Copper Creek carries very little water except during the torrential thunderstorms that occur occasionally in the summer months. The climate is arid and warm.

PROSPECTING AND EXPLORATION

The first serious prospecting on the Bagdad claims was done in 1906, when the Giroux Syndicate acquired 8 patented and 12 unpatented claims and drove an adit into the banks of Copper Creek. A small amount of high-grade copper ore was mined and hauled by wagon to Prescott, but the venture was unsuccessful. In 1911 the Bagdad Copper Co. gave an option to the General Development Co., of New York, N. Y., which drilled 11 churn-drill holes before relinquishing the option. About 130 churn-drill holes had been drilled by the present operating company by 1928, and this work outlined the ore body essentially as it is known today.

ESTIMATE OF TONNAGE AND GRADE

A sample was split from each 5-foot interval in the churn-drill holes and assayed for total copper. These samples were used to compute grade and tonnage. Beginning with plans for expansion in 1946, holes were drilled with a diamond drill. About 149 diamond-drill holes (a total of 54,000 feet) were completed and sampled by 1953. The original churn-drill holes did not bottom the ore and were assayed for total copper only. The cored holes were continued in depth until core samples assayed less than 0.4 percent copper.

Some additional holes are being drilled as the mine is developed. These diamond-drill holes are begun and drilled to depths of 50 to 100 feet with a BX bit, and then finished with an AX bit. Both sludge and core are sampled and assayed. The core and sludge assays are combined by a weight-factor method that favors the core to give the accepted assay. When more than 80 percent of the core is recovered, the assay of the core is accepted without correction. Composite samples for 50-foot intervals are made and assayed for gold, silver, molybdenum, and other components.

In the main parts of the ore body sample holes are spaced at 100-foot intervals, but in the outlying fringes they are spaced at intervals of 200

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feet. The ore body is divided into 50-foot levels. A map of the level is divided into areas so that each drill hole has about equal weight and tonnage. The grade of each area is calculated by averaging the assays for the level interval. A factor of 12-1/2 cubic feet per ton of ore in place is used.

Using a cutoff grade of 0.5 percent copper, the last published figures (1954) showed a reserve of 30 million tons of sulfide ore containing 0.754 percent copper.5/ The sulfide ore also contains about 0.5 pound of molybdenum sulfide per ton. At the same time, 300 million tons of oxide-carbonate leach ore was estimated by using a cutoff grade of 0.15 percent copper. The final waste-ore ratio was estimated at 3:1.

The calculated grade compared with that of the ore actually mined in some completed areas is shown in table 2.

TABLE 2. - Calculated and actual assay

Bench	Area	Tons	Copper, percent	
			Calculated	Actual
8	4	303,905	0.640	0.622
7	3	294,786	1.040	.961
7	4	183,907	.880	.870
6	5	102,496	.760	.760
6	4	99,024	.900	1.434

DEVELOPMENT

The Bagdad mine first was developed as an underground mine. This stage in the life of the property has been described.6/ From 1936 to 1945, ore was mined by the block-caving method. Several serious problems developed. The high-grade sulfide ore zone was relatively thin; ore suitable for underground mining averaged 125 feet thick. During World War II, competent underground miners were scarce. Boundary drifts and corner raises were required to facilitate caving. All this added up to a relatively high footage of development work per ton of ore. Moreover, because the ore did not fracture well and the ore body was thin, dilution was a problem. The maximum average rate of production achieved by the caving operation was approximately 1,500 tons per day.

Where Copper Creek cut through the ore body, the high-grade chalcocite ore was very close to the surface (fig. 7). A contract was made for removing the thin blanket of waste covering this area, and a raise from underground workings was driven to the surface. Ore then was blasted at the surface, bulldozed into the raise, drawn off below, trammed to the main shaft, and hoisted to the surface. The mining cost was improved temporarily, and the rate of production increased. This glory-hole method was successful, but it

5/ Parsons, A. B., The Porphyry Coppers in 1956: AIME, New York, N. Y., 1957, p. 1921.

6/ Hardwick, W. R., Block-Caving Mining Methods and Costs at the Bagdad Mine, Bagdad Copper Corp., Yavapai County, Ariz.: Bureau of Mines Inf. Circ. 7890, 1959, 28 pp.

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was obvious that it could be applied only to a limited part of the ore body. Furthermore, it immediately became apparent that economies would result if surface haulage were substituted for the underground transportation system, and the decision was made to convert the mine to an open pit.

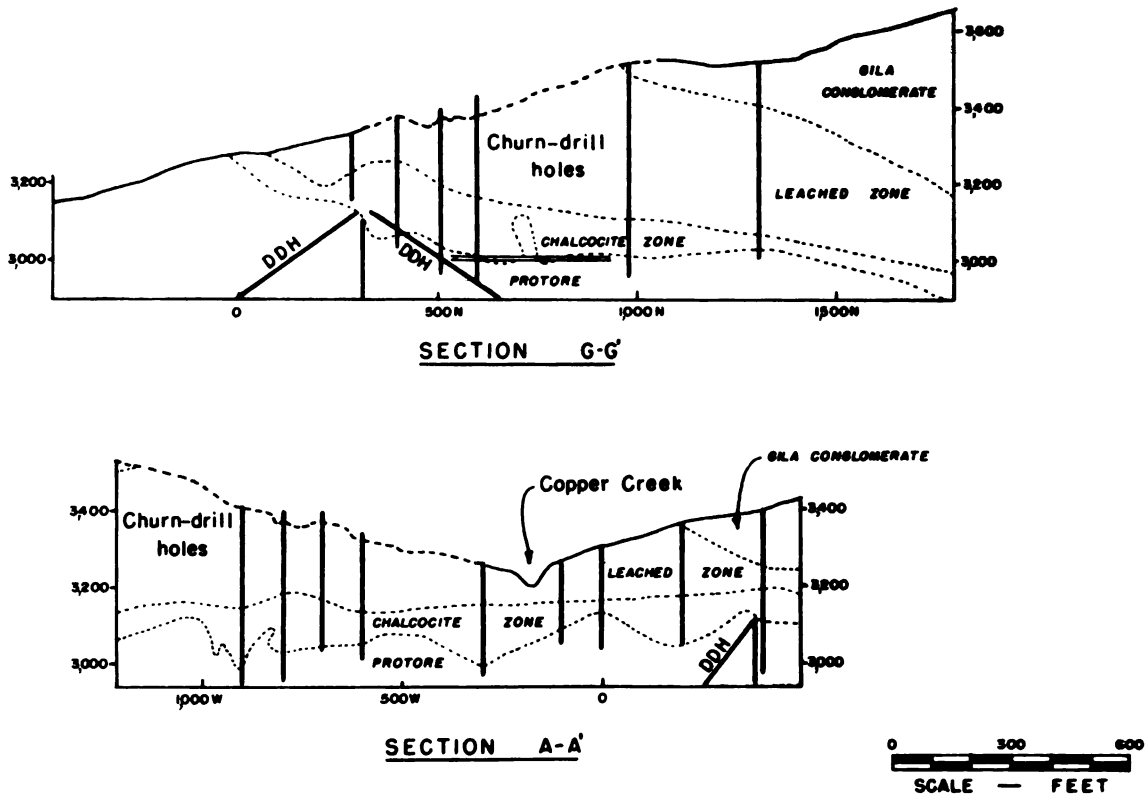

FIGURE 7. - Sections Through Bagdad Mine.

In the interval from 1945 to 1948 the company secured open-pit mining equipment of its own, terminated the stripping contract, and prepared a surface transportation system to haul the ore to the concentrator. As this surface haulage was developed, the underground operation was suspended. After 1948 all ore was mined by the open-pit method.

Only a small amount of stripping in addition to that already completed for the glory-hole operation was necessary before mining by the open-pit method could be started; however, part of the ore body is on the east side of Copper Creek under heavy overburden, which must be moved before the ore can be mined. So that this overburden may be removed by the time the easily available open-pit ore along the channel of Copper Creek is mined, the stripping has been accelerated. Present plans for the open-pit operation indicate a final stripping ratio of about 3 tons of waste for each ton of ore, but during 1957 waste was moved at the rate of 10 tons per ton of ore mined.

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MINING

The mining method now used is a multiple-bench open-pit system. The pit is roughly oval and measures 2,000 by 2,500 feet on the axis. Multiple rows of holes, 5 to 7 inches in diameter, are drilled with churn or rotary drills along 50-foot benches and loaded with a quarry-type blasting agent. The explosive is fired with primacord, which is exploded with cap and fuse. The broken rock is loaded by full-revolving electric- or diesel-powered shovels into trucks, which haul 20 to 60 tons, and transported to the crusher or to the waste dumps. Rock containing oxidized copper is separated from barren waste and dumped where it will be available for future treatment. Ore is hauled to a coarse crusher near the pit, crushed to minus-5-inch, and then conveyed by a 983-foot belt, operating at an incline of plus 17.5°, to the storage bins at the head of the concentrator.

The mining cycle falls naturally into the processes of breaking, loading, transporting, and disposing of ore and waste. These steps are discussed in the following sections.

Breaking Ground

Breaking ground in the Bagdad open pit is complicated by the presence of four types of rock: Basalt, Gila conglomerate, oxidized monzonite capping, and unoxidized monzonite or sulfide ore. Each type has different characteristics that affect drilling and blasting. Breaking ground is divided into drilling holes along 50-foot-high banks (primary drilling), loading the holes with explosive (primary blasting), and breaking large boulders that remain (secondary drilling and blasting).

Primary Drilling

The first blastholes were drilled in the open pit at Bagdad by gasoline-driven churn drills. Blastholes having a diameter of 10 to 12 inches have been tried. These larger holes were more widely spaced, and fragmentation was not satisfactory, particularly in the upper part of the bank. The high powder column in holes of about 7 inches in diameter resulted in fewer ragged crests, and when the mine was visited in mid-1957, drilling holes 6 to 7 inches in diameter was standard practice.

Holes were drilled along the crest of the bank to a depth of 5 feet below grade. Multiple rows of holes were used; the outside row was about 10 feet from the crest of the bank. Holes were spaced from 12 by 12 feet in hard ore to 20 by 20 feet in soft ground. An average of 1,600 tons of material was broken per drill hole.

Two types of blasthole churn drills now are used; both are classified as light drills according to current open-pit drilling practice. The larger of the two drills is equipped with a 40-foot derrick and weighs about 21,500 pounds without tools or cable. This machine is powered by a 6-cylinder, 45-hp. gasoline engine and is capable of swinging tools that weigh up to 2,000 pounds. The smaller drill is equipped with a 34-foot 7-inch derrick and weighs about

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12,000 pounds. It is powered with a 4-cylinder, 29-hp. gasoline engine and is capable of swinging tools that weigh up to 1,500 pounds. Both drills are self-propelled by a friction-clutch arrangement and are mounted on crawl-type tracks.

Churn-drill bits are heated in an oil-burning furnace and sharpened in an electrically powered bit sharpener. The bits weigh about 250 pounds when new and are handled by the crew without help from any mechanical handling device. A bit-sharpening crew consists of three men - one operates the machine and two handle the bits. Churn-drill bits average 25 feet in the ore and 40 feet in the waste for each time sharpened. Drilling rates of the churn drill in the various types of rock in the Bagdad mine are shown in table 3.

TABLE 3. - Drilling rates at Bagdad mine

Type of rock	Feet per shift	
	Churn drill (7-inch hole)	Rotary drill (6-3/4-inch hole)
Basalt.....	60	200
Gila conglomerate.....	110	350
Monzonite:		
Capping.....	85	275
Sulfide.....	50	160

Two makes of rotary drills are used at Bagdad. One, a Joy 225, is mounted on a standard truck chassis having a 233-inch wheelbase. A piston compressor furnishes 359 c.f.m. of air at 125 p.s.i. A separate diesel motor supplies power for the drill head and air compressor through a gearbox. A 40-foot mast accommodates 30-foot lengths of 3-1/2-inch-diameter hollow drill stem above the rotary table, which rotates at 49 to 139 r.p.m.

The other rotary is a Winter-Weiss Portadrill. It is mounted on a D6 Caterpillar tractor. Two 300-c.f.m. vane-type compressors furnish air at 45 p.s.i. The tractor engine furnishes power for the drill table and compressors through power takeoffs. This rig will accommodate 26-foot lengths of drill stem.

Both drills use a standard roller-cone bit, and the cuttings are removed by air. Roller-cone bits drill an average 560 feet before being retipped. After retipping, the bits will drill about 200 feet. Most bits can be re-tipped two times. Drilling rates of the rotary drill in the various types of rock in the Bagdad mine are shown in table 3.

When the mine was visited in June 1957, most blasthole drilling was contracted to an outside contractor on a "per foot" basis. The contractor furnished drills, all equipment, supplies, and labor. A drill similar to the small rotary described was used. Two machines were operating. Drill performance in ore and waste is shown in table 4.

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TABLE 4. - Drill performance in ore and waste (1957), all types of rock

Type of drill	4-month period	Per shift
Rotary drill:		
In ore.....feet	4,298	148.2
In waste.....do.	48,087	329.4
Churn drill:		
In ore.....do.	24,743	53.7
In waste.....do.	29,092	83.5

Primary Blasting

Thirty to thirty-five holes are drilled for an average blast. The 7-inch drill holes are loaded with ammonia dynamite, gelatin dynamite, or ammonium nitrate and fuel oil. Plastic explosives are packed in 5- by 24-inch cartridges, free-flowing explosives are in 12-1/2-pound bags, and ammonium nitrate is in an 80-pound bag. The ammonium nitrate is opened at the hole, and about a gallon of light fuel oil is poured into the bag; then the contents are dropped down the hole. When ammonium nitrate is used, two or three cartridges of gelatin dynamite are used as a primer for the charge, which is detonated with primacord. High-velocity primacord is on trial as a substitute for the dynamite primer. The 400-grain primacord is cut in 1-foot lengths and tied at 3-foot intervals on the regular 50-grain primacord line through the charge of ammonium nitrate.

Two grades of explosive are used, one 60-percent strength and the other 20- to 30-percent strength, in about equal amounts. The powder foreman, an experienced man, judges the amount of explosive to be used in each hole, taking into account the burden, hardness, and type of formation. A typical charge in ore is seven cases, or 350 pounds, of explosive, which rises about 21 feet in a 55-foot hole and leaves 34 feet for stemming. In weathered conglomerate a lesser charge is used, and the stemming column is about 40 feet. Fine material from the bank or rotary-drill cuttings is placed in the holes by a rubber-tired front-end loader for stemming. In the Gila conglomerate and in other material that tends to hang up in the crest of the bank, holes may be deckloaded with 50 to 150 pounds of blasting agent to bring the charge near the top of the hole. Better fragmentation results when a slow-speed explosive of 20- to 30-percent strength is used in the conglomerate. The explosive consumption at Bagdad ranges from 0.15 pound per ton in average ground to 0.20 pound per ton in hard ground.

Two lines of regular primacord, or one line of plastic reinforced primacord, are carried to the bottom of the hole. The leads are tied to a main trunkline of plain primacord, and a cap is fastened at each end. The caps are fired with fuse. Blasts are fired between shifts, when most of the employees are out of the pit.

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Secondary Drilling and Blasting

Secondary drilling has minor importance in the Bagdad mine. The rock is broken well by primary blasts. The blasting of only three or four boulders per week is required, and these are broken by mudcap shots. When hard bottom occurs, a few holes are drilled with jackhammers and blasted. Air for secondary drilling is furnished by a 225-c.f.m. portable compressor, driven by a diesel motor.

Loading

Six full-revolving shovels currently are used at the Bagdad mine; two are diesel, and four electric powered; their capacities range from 2-1/2 to 8 cubic yards. The smaller shovels are used in the pit to load ore, and the larger shovels are employed almost entirely on waste. Loading performances of the various shovels during a 4-month period early in 1957 are shown in table 5.

TABLE 5. - Loading-equipment performance (1957), tons

Shovel size, yards	4-month period	Per shift
2-1/2 (diesel):		
In ore	12,993	1,677
In waste	851	1,702
3 (diesel):		
In ore	145,198	2,536
In waste	226,278	3,328
3-1/2 (electric):		
In ore	222,799	2,422
In waste	15,419	3,084
4-1/2 (electric):		
In ore	104,398	3,212
In waste	647,411	4,338
6 (electric):		
In ore	-	-
In waste	1,638,666	8,204
8 (electric):		
In ore	-	-
In waste	1,536,578	9,500

Banks are 50 feet high, and benches range from 40 to 100 feet in width. This usually is too narrow for the shovel to load from both sides, and only one truck is loaded at a time (fig. 8). Trucks usually are loaded from the operator's side to provide better visibility. When a shovel is moved up or down a ramp from bench to bench, a crawl-type tractor with a tow cable is used to hold back and prevent excessive strain on the travel and brake mechanisms of the shovel.

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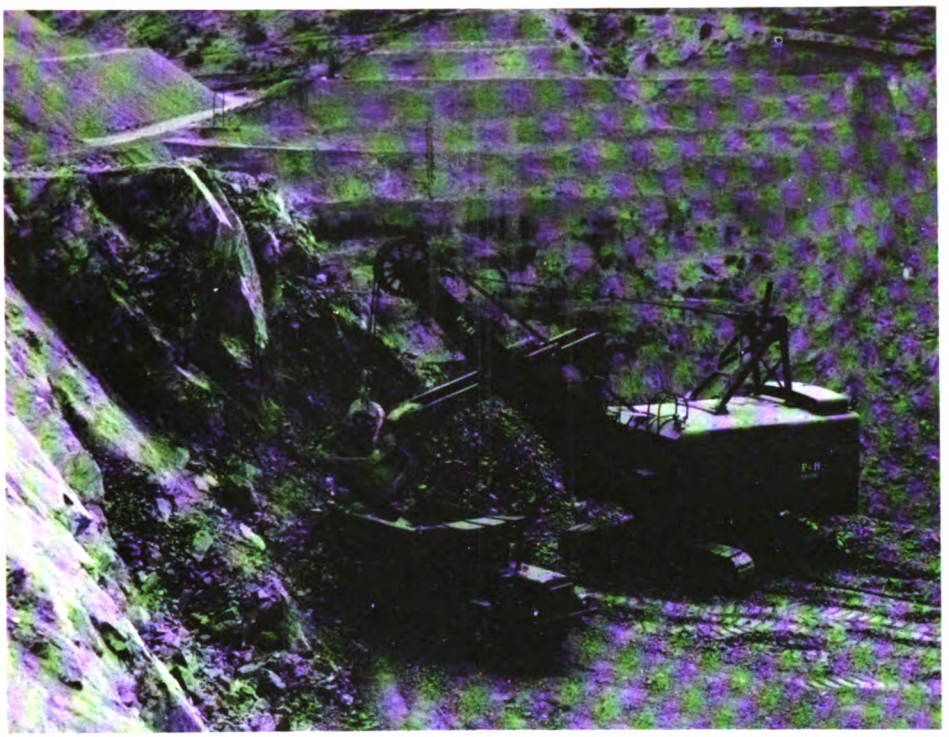

FIGURE 8. - Shovel-Loading a Single Truck.

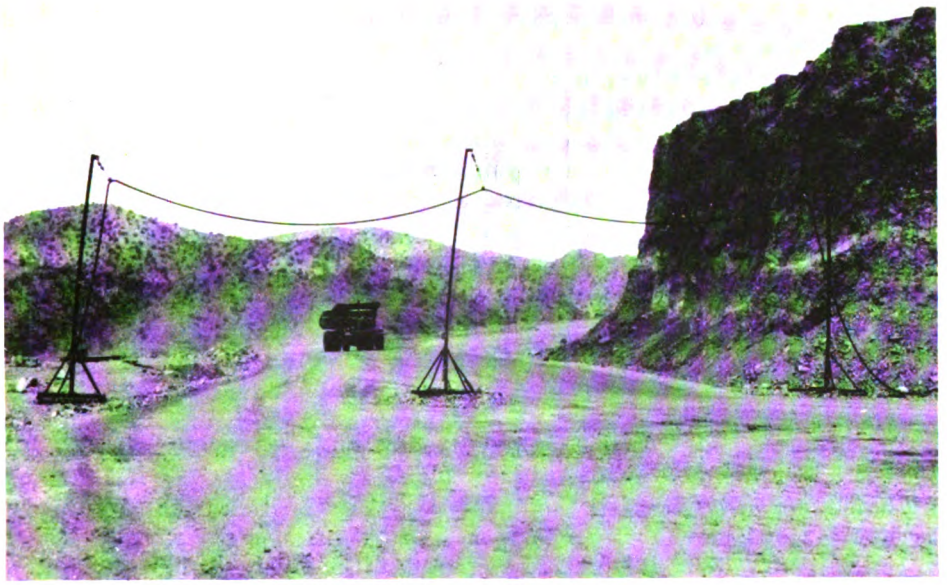

FIGURE 9. - Truck Haul Road.

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Power is purchased from the Bureau of Reclamation, at Parker, Ariz., and brought to the mine over a 70-mile high-tension transmission line. At the mine the voltage is reduced to 2,300 volts. Power is carried to the north side of the pit on a high line and then is conducted to the shovel by a four-strand insulated cable. Portable towers, weighted at their bases, are used to support the cable over haul roads (fig. 9). At the top of each tower is a pulley through which is threaded a light rope with an insulated clamp on one end. To raise the cable, the clamp is fastened, the cable is hoisted to the required height, and the rope is made fast.

Transportation

Transportation at the Bagdad mine presents a major problem.[7/] The canyon-like valley of Copper Creek is bordered on both sides by high mesas. The concentrator is on a high ridge very close to the ore body at an altitude of about 3,308 feet. The upper bench in the sulfide ore is at 3,230 feet; the lower bench (as now planned) will be at 2,800 feet. Ore is transported by a combination truck-conveyor system;[8/] waste and leach material are hauled by trucks. Waste is hauled to dumps along Copper Creek beyond the north limit of the ore body, and carbonate ore is hauled to a dump in an area suitable for future leaching. The sulfide ore is hauled to a crusher at the edge of the pit, crushed to minus-5-inch, and conveyed by belt 983 feet up a slope at 17.5° to the concentrator bin. This raises the ore a vertical distance of 293 feet and eliminates an expensive haul by truck up steep grades.

Truck Haulage

Truck haulage over adverse grades of 8 to 16 percent is necessary. Recognizing the problem, the Bagdad Copper Corp. endeavored to determine which haulage units gave the best performance and what conditions led to rising costs. A careful cost analysis for each make and type of haulage unit has been a most important means of determining which gives the best performance. Cost records at Bagdad have indicated that the use of larger units generally results in lower costs. With this incentive, one company designed a truck for 60-ton payloads, which later was modified to carry 75 tons. Some major changes in the design of this unit included dual front wheels, center swivel- or wagon-type front-axle assembly, front-end suspension on hydraulic-air strut, full-box section frame, and twin motors mounted amidship. The truck weighed 96,000 pounds empty. It was powered by two 350-hp. diesel motors, each driving a separate axle through torque converters. Reported to be the world's largest truck,[9/] it was operated for over 2 years. Although it hauled record payloads, this truck was plagued with mechanical difficulties and did not compete cost-wise with somewhat smaller and more conventional units.

7/ Mining World, This is What Streamlined Mining and Improved Haulage Did for Bagdad: Vol. 16, No. 9, August 1954, p. 40.

8/ Colville, George W., The Bagdad Open-Pit Conveyor: Min. Cong. Jour., vol. 41, No. 7, July 1955, p. 24.

9/ Mining World, World's Largest Truck to Bagdad Copper: Vol. 15, No. 4, April 1953, p. 73.

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Torque converters were first used at Bagdad in 1950 on 30-ton trucks. Their use is credited with materially reducing maintenance costs, reducing brake repairs by 75 percent, and increasing tire mileage by 35 to 50 percent.10/

When the mine was visited in June 1957, several different types of haulage equipment were being used; table 6 lists these with their performance over a 4-month period in early 1957. During this period material was hauled an average of 0.55 mile. The smaller trucks are used for hauling ore, and the larger ones for hauling waste.

TABLE 6. - Haulage-equipment performance

Haulage unit	Number of units	Tons hauled	Tons per mile traveled	Tons per hour operated	Miles per gallon of fuel	Time operated, percent
End-dump truck:						
20-ton	5	147,228	19.11	83.35	0.6855	9.7
22-ton (with torque converter)	10	3,100,105	17.19	97.50	.8662	63.1
22-ton (without torque converter)	4	535,933	19.64	87.00	.6201	30.8
30-ton	10	5,346,676	20.44	136.10	.8324	77.1
40-ton, diesel	6	3,538,162	31.39	161.70	.6308	71.8
40-ton, butane	2	59,172	27.10	137.26	.3326	
50-ton	1	756,670	37.46	202.79	.5892	73.7
Tournarocker:						
40-ton	2	25,414	25.09	122.18	.4355	11.4
50-ton	1	60,573	31.66	137.04	.3377	14.3
Total and average...	41	13,569,933	22.22	128.70	-	59.1

Ore is hauled an average of 0.7 mile over an adverse grade of 12 percent and as much as 16 percent when the lower levels of the mine are operated. The ore haul begins on a level bench, which ranges from 40 to 100 feet in width and is relatively straight. The adverse-grade part of the haul may have several sharp curves. A typical run for an ore truck would include 0.35 to 0.45 mile of level haul, 0.15 to 0.25 mile at an adverse grade of 12 to 16 percent, and finally 0.10 mile approximately level to the crusher.

Carbonate leach material is hauled to the southwest of the pit and dumped where it can be leached later. A fill has been built across Copper Creek; the adverse grade on this haul is about 1.8 percent, and several curves are required. Waste from the upper levels is hauled northeast along Copper Creek above the mine to a point beyond the ore body and dumped to form a dam across the creek. Here the grade usually is less than 8 percent; the distance is

10/ Dickie, Ernest R., Colville, George W., Hondrum, Olaf, and Green, George, New Ideas for Bagdad Copper: Eng. Min. Jour., vol. 154, No. 3, March 1953, pp. 89-93.

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about 2,500 feet. Waste from the intermediate levels is hauled northwest along Copper Creek below the mine and dumped beyond the limit of the ore body; the distance is about 1 mile.

All roads are wide enough for trucks to pass each other at any place (fig. 9). Roads are kept smooth with a Tournadozer and a motor grader, and all haul roads are sprinkled continuously with a sprinkler truck when they are being used. Left-hand traffic is required on all roads in the pit. This enables the driver to see the outside of the road better, and there is less danger of driving off the bench or hitting rocks along the edge of the road. The shift foreman establishes a driving procedure for each haul, and all trucks are required to retain their place in the cycle. Empty trucks are not allowed to race back to the shovel.

New drivers are trained by a driver instructor; he continues instruction of the older drivers as required. He also serves as liaison between the pit and shop on safety and operation of trucks. Particular attention is given to the condition and proper operation of brakes and steering apparatus. If both transmission and brakes are operated by air, auxiliary air tanks and check valves are provided to prevent the loss of both brakes and transmission should an air line break. Drivers are instructed to bring the truck to a stop if they consider its operation unsafe in any way.

Tournarocker-type units first were used as prime movers in open-pit mining at the Bagdad. The first units had 40-ton capacities; however, their availability was low, owing largely to time out for mechanical difficulties and repairs. The 50-ton Tournarockers (purchased in 1951) have a capacity of 33 yards and are equipped with torque converters. These units do not fit in with the trucks on a haulage cycle and are used to haul ore.

Haulage equipment at the Bagdad mine is available about 70 percent of the time. The mileage of tires on trucks equipped with torque converters and rear springs is about 30 percent more than on the dead-axle-type trucks with standard transmission. Maintenance costs of trucks equipped with torque converters were considerable lower than those of trucks not so equipped; however, the cost of fuel was up about 10 percent.

The diesel motors in the trucks operate approximately 6,000 hours before the first overhaul. These motors run from 3,000 to 5,000 hours before again requiring a complete overhaul. A four-bay truck shop is available for truck repairs. The diesel motors are repaired in the shops but are not rebuilt there. When a motor requires rebuilding, it is sent to an outside contractor. All tire-repair work also is contracted to an independent shop.

Trucks built by several different manufacturers and with several power-train arrangements are used. The performance of several types of units is shown in table 6.

Conveyor Haulage

There is a difference in elevation of about 375 feet between the present lowest working level and the mill bins, and this difference will increase as

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the pit becomes deeper. A conveyor system was installed to eliminate a steep truck haul.

A site was selected at the edge of the ore body where a minimum amount of ore would be tied up. A truck dump was designed where trucks dump over a 5- by 12-foot scalping screen with 5-inch openings. The oversize from this screen is passed into a 42- by 40-inch jaw crusher. The crushed product joins the undersize from the screen and is fed to a 36-inch by 160-foot stacking conveyor, which raises it at 12.5° and discharges into a 5,000-ton storage pocket. Ore is drawn from the bottom of this storage pocket and fed by a 36-inch by 8-foot pan feeder onto the main conveyor belt. This belt (fig. 10) is 36 inches wide by 983 feet long; it elevates the ore 293 feet to the fine-crushing and screening plant near the concentrator. The belt is driven by a 65-hp. electric motor and travels at 285 feet per minute. The speed can be increased if necessary to increase capacity.

Before the belt system had been completed it was necessary to mine ore on each shift that the mill was operated (21 shifts per week). After the belt system, including the 5,000-ton-pit storage pocket, was completed, the mine operation was reduced to 12 shifts per week, but the mill and belt continued to operate 21 shifts per week. The cost of transporting ore was greatly reduced.

Engineering and Operating Control

Engineering assistance is available, but the primary responsibility for ore control rests with the operating foreman. A map of the mine topography (fig. 11) shows the elevations of mining benches by contour rather than by symbol for crest and toe. This map is drawn on a scale of 100 feet per inch, and the positions of the diamond- or churn-drill sample holes are plotted. The holes are spaced 100 feet apart in ore areas, and this is considered to be close enough for the operating foreman to segregate ore from waste. The holes drilled for blasting are not sampled, but when the grade of the ore in an area is doubtful, the mine foreman has a few grab samples of the broken rock analyzed. Ore and waste in the bank generally are recognized readily by visual inspection.

To estimate the grade for the day, the mine foreman takes the contour nearest the shovel, checks the nearest sample drill hole, and reads the grade from the log of the hole at that elevation. The grade of the mill heads ranges from 0.5 to 1.5 percent copper.

Summary of Mine Equipment

Mining equipment was selected to best fit the physical conditions imposed by the topography and rock characteristics at Bagdad. Smaller type blasthole drills were selected because they could be moved more easily along the rough escarpment of Black Mesa and because it has been proved that smaller, more closely spaced blastholes result in better fragmentation.

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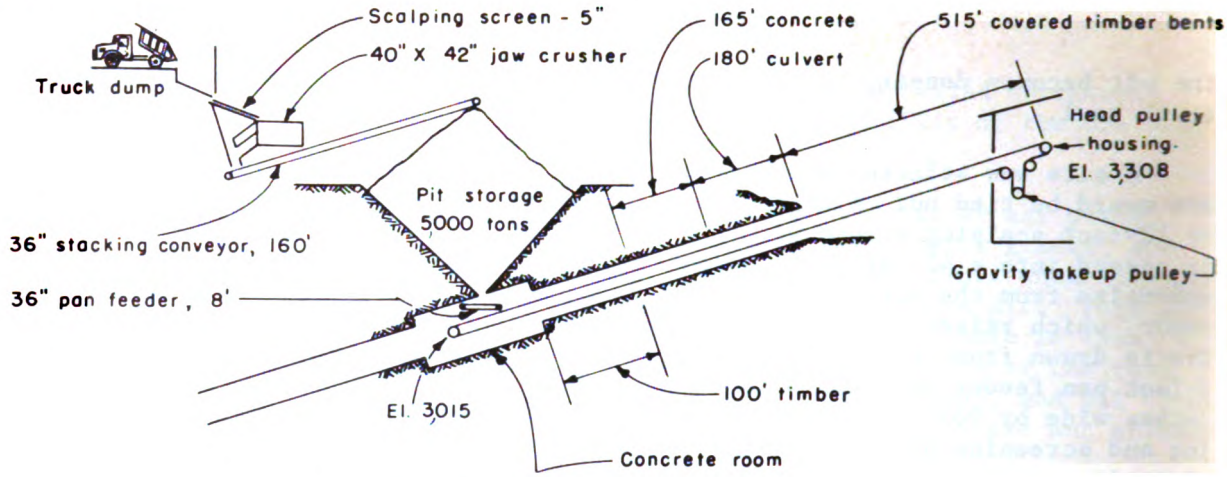

FIGURE 10. - Sketch of Pit-Conveyor System.

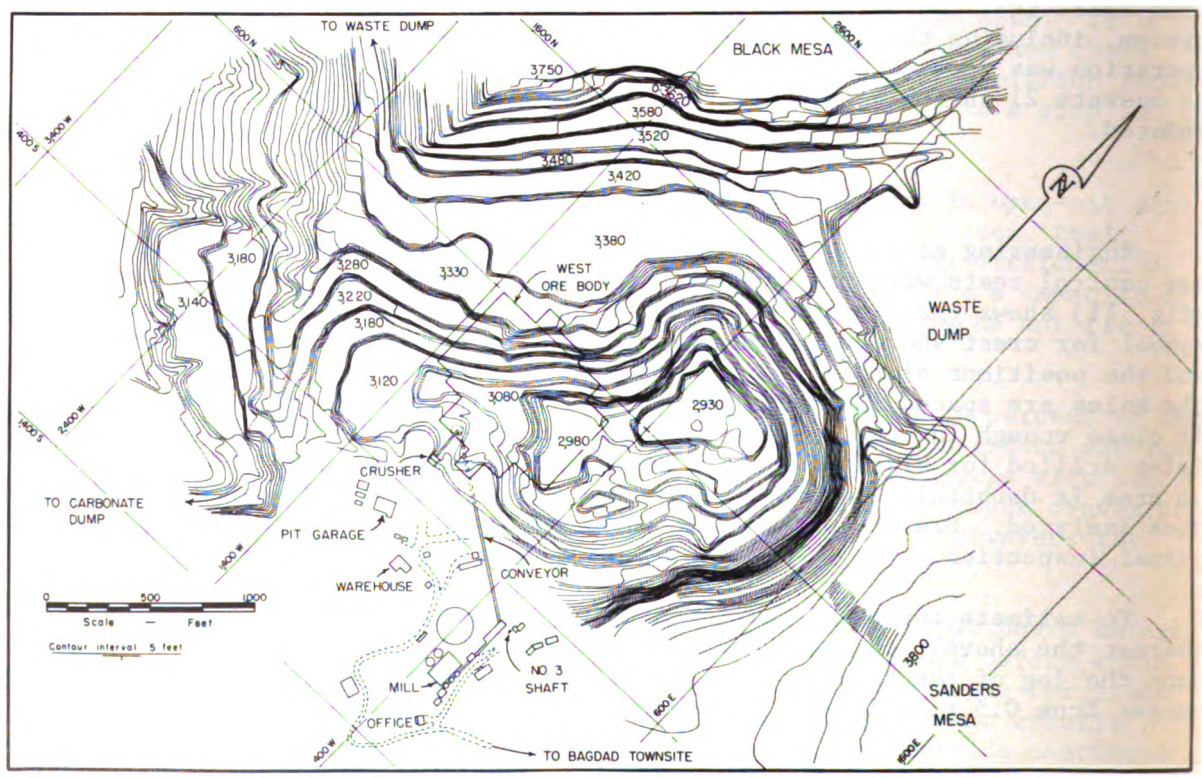

FIGURE 11. - Pit Topography, Bagdad Mine.

Small shovels are selected to load ore where maneuverability is more important than capacity. Intermediate-size shovels are used on the higher stripping levels where some mobility is required. Heavy shovels are used in carbonate ore or waste on established benches where a high production rate can be used to advantage.

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Haulage has been one of the serious problems at the Bagdad. To find the most economical equipment, the company operated haulage equipment from different manufacturers side by side. A careful cost analysis for each make of haulage unit is kept by the company.

A specially designed truck with 75-ton capacity has been mentioned. In addition, trucks built by several companies in each size are operated. Different manufacturers also supply motors for the same size trucks. Motors adapted to butane fuel were on trial when the plant was visited in 1957.

A summary of mine equipment in use at the Bagdad is given below.

	Number of units
Drilling:	
Diamond drills, skid-mounted, surface type	2
Churn drills:	
1,500-pound tools	2
2,000-pound tools	3
Rotary drills (6-3/4-inch holes)	2
Compressor, 225-c.f.m., trailer-mounted	1
Loading:	
Shovels:	
2-1/2-yard, track-mounted, diesel-powered	1
3-yard, track-mounted, diesel-powered	1
3-1/2-yard, track-mounted, electric-powered	1
4-1/2-yard, track-mounted, electric-powered	1
6-yard, track-mounted, electric-powered	1
8-yard, track-mounted, electric-powered	1
Front-end loader, 1-1/2-yard	1
Haulage:	
End-dump trucks:	
22-ton	19
30-ton	10
50-ton	1
55-ton	8
Tournarockers:	
40-ton	2
50-ton	2
Tractors:	
Large, track-mounted	5
Small, track-mounted	1
Large, rubber-tired	3
Miscellaneous:	
Scraper, 11-yard	1
Ripper	1
Road graders	3
Trucks:	
Drill service	1
Sprinkler, 4,500- and 2,500-gallon capacity	2
Grease	1
Boom crane	1
Forklift	1

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PERCENTAGE EXTRACTION AND PRODUCTION RATES

The ultimate extraction of sulfide ore will depend on the final stripping ratio. Based upon the 1953 estimate, the mining of 30 million tons of sulfide ore will require the removal of 30 million tons of oxide ore and 39 million tons of waste. The final percent extraction of the copper depends on the development of a satisfactory method of extracting the copper from the low-grade oxide ore that is being stored in a separate dump. The solution of this problem has been carried through the pilot-plant stage successfully.

The initial pilot flotation plant (built in 1929) had a daily capacity of 50 tons. This plant was enlarged to 200 tons daily in 1931. In 1943 the mill was moved and completely rebuilt with a daily capacity of 2,500 tons. The capacity was increased to 4,000 tons daily in 1950 by adding a fourth ball mill and to 5,000 tons in 1957 by a fifth ball mill. The company plans to increase production to 10,000 tons daily by gradually expanding the mine and plant.

MINE DRAINAGE AND WATER SUPPLY

The mine produces only about 150,000 gallons of water daily. This collects in the old underground workings and is pumped from the shaft and used in the mill. In 1943 pickup pumps were installed in a natural sump on Burro Creek to pump surface runoff water, and about 7-1/2 miles of 10-inch pipeline was constructed. Water is pumped to the mill by electrically driven centrifugal pumps against a head of 1,100 feet. Future plans call for increasing the water supply by drilling additional wells and building a 200-foot dam across Burro Creek to impound floodwaters. The tailings pond was constructed to provide a settling pond. Nearly all water in the tailings is recovered and reused.

A waste fill has been constructed across Copper Creek above the open pit to prevent the mine from being flooded by flash floods.

WAGE, CONTRACT, AND BONUS SYSTEMS

All employees are on a straight hourly wage, except for supervisory and engineering employees, who are on salary. All employees, both wage and salary, participate in a profit-sharing program.

Some work, such as blasthole drilling, diesel-engine rebuilding, and tire repair, is contracted outside on a cost-per-unit basis.

The total number of employees in the plant is about 325. The mine has approximately 175, the mill 80, and the remainder are employed in the machine shop, accounting, and other accessory facilities.

SAFETY AND FIRE PREVENTION

Safety is the responsibility of management and supervisors. First-aid classes are held annually by management in cooperation with employees of the

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Safety Branch of the Federal Bureau of Mines. Accident-prevention classes are held for supervisory personnel, also in cooperation with the Bureau of Mines. Safety suggestions by management through supervisors receive prompt attention by employees. An engineer is in charge of safety organization.

A volunteer fire crew practices regularly with equipment furnished by the company. Fire extinguishers of suitable types are placed in strategic positions.

PROCESSING PLANT

A complete description of the processing plant is beyond the scope of this report. Metallurgy has played an important part in the success of the Bagdad operation and will continue to do so in the future. A significant part of the copper in the deposit is in oxide, carbonate, and silicate minerals and is not recovered by the present flotation process. Much research has been done on the problem, however, and ores of that type are being treated successfully in a pilot plant.

Present Sulfide Concentrator

The capacity of the flotation concentrating plant, built in 1943 with a designed capacity of 2,500 tons, has been increased by improvements in the crushing practice and by increasing the number of ball mills from three to five. The present capacity (1957) is 5,000 tons per day, and the company expects to increase this to 10,000 tons per day. The general arrangement of the flowsheet is shown in figure 12.

Ore is mined and the coarse-crushing plant is operated two shifts per day to supply the mill with the required tonnage. The pit conveyor (fig. 13), drawing from the 5,000-ton pit storage, and the concentrating plant are operated three shifts per day. Ore is crushed in three stages to minus-3/8-inch mesh and then ground in 8- by 9-foot ball mills, and a combined copper-molybdenum concentrate is made in 66-inch mechanical flotation cells. Copper concentrate passes through 56-inch mechanical cells, and a rough molybdenum concentrate is separated and cleaned eight times to produce a final product that contains 93 percent MoS_2 and about 0.5 percent copper. The copper concentrate contains about 34 percent copper, 22 percent iron, and 9 percent insolubles. The copper concentrate is trucked to Hillside by contract, shipped by rail, and sold to a custom smelter. Some metallurgical information is listed below.

	Percent		Percent
Heads:		Concentrate (Con.):	
Total copper	0.8	Copper (Con.):	
Oxide copper	1/ 14.5	Sulfur	27.0
Molybdenite	.025	Insolubles	9.0
Concentrate:		Molybdenum:	
Bulk:		MoS_2	93.0
Copper	34.0	Copper	.5
Molybdenum	1.58		
Copper:		Copper recovery:	
Copper	34.0	Sulfide-copper	94.7
Iron	22.0	Total copper	84.3

1/ Percent of total Cu.

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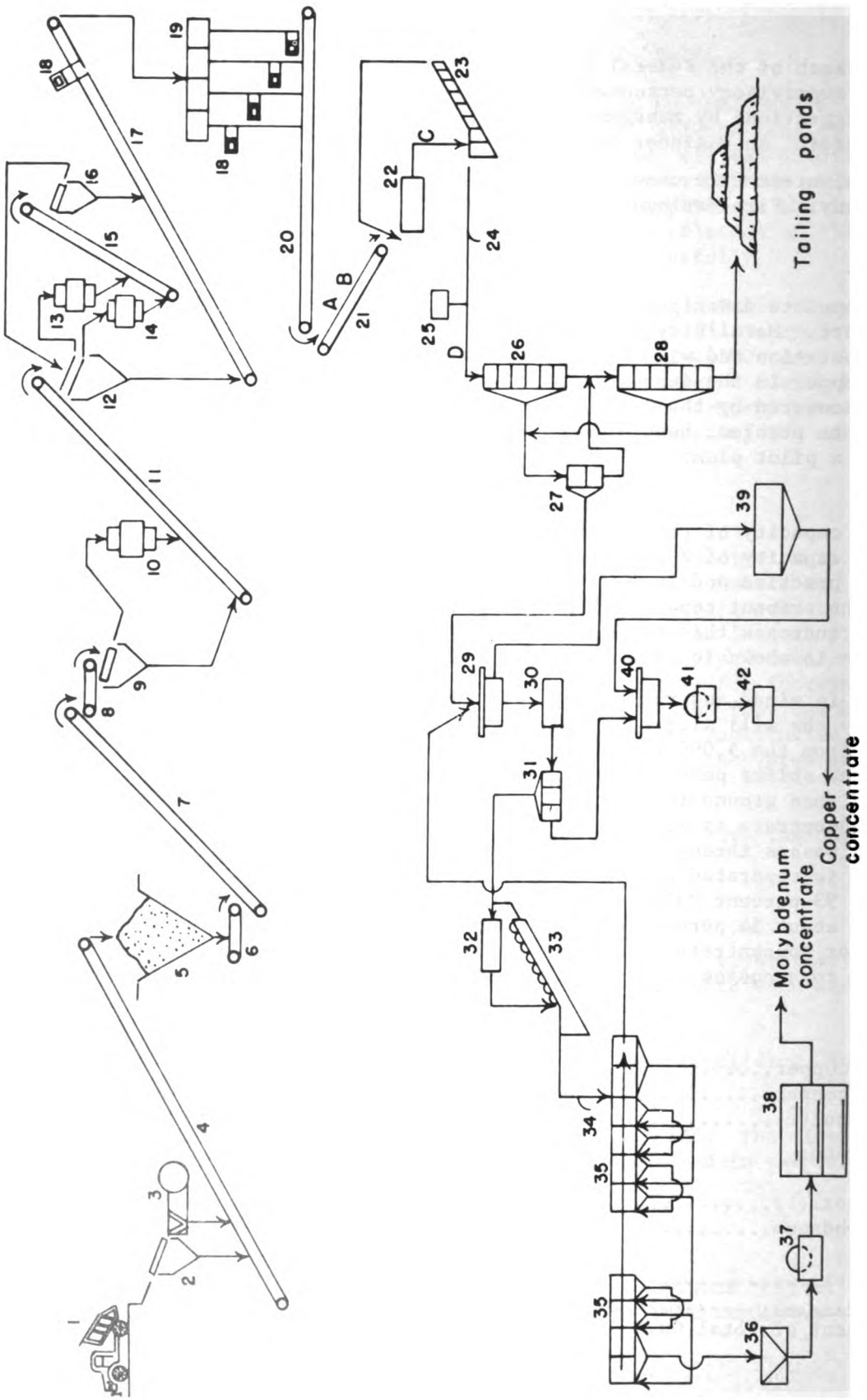

FIGURE 12. - Mill Flowsheet, Bagdad Copper Corp.

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A key to the numbers and letters used in figure 12 follows:

1. Ore entry (5,000 tons per day; 2-shift operation).
2. Scalping screen (5-inch openings).
3. Jaw crusher (42- by 40-inch jaws).
4. Stacking conveyor (36 inches by 160 feet at +11°).
5. Pit storage pocket (5,000 tons).
6. Pan feeder (36 inches by 8 feet).
7. Pit conveyor (36 inches by 983 feet at +17.5°).
8. Feeder conveyor.
9. Grizzly (3-inch openings).
10. Gyratory crusher (2-1/2 to 3 inches).
11. Conveyor (30-inch width).
12. Two-deck vibrating screen (3/4 and 1/2 inch).
13. Cone crusher (3/8 inch).
14. Do.
15. Conveyor (36-inch width).
16. Vibrating screen (3/8 inch).
17. Conveyor (24-inch width).
18. Weightometer.
19. 4 storage bins (1,000 tons each).
20. 4 conveyors (18-inch width).
21. Ball-mill feed.
22. Ball mills (8 by 9 feet, 5 used).
23. Classifier (3 rake, 2 spiral).
24. Overflow from classifier.
25. Reagent feeder.
26. Primary flotation, 66-inch mechanical cells (3 units of 6).
27. Cleaner flotation, 56-inch mechanical cells (3 units of 2).
28. Scavenger flotation, 66-inch mechanical cells (3 units of 6).
29. Thickener (40-foot diameter).
30. Conditioner.
31. Molybdenum flotation.
32. Regrind ball mill (3 by 3 feet).
33. Spiral classifier.
34. Overflow.
35. Molybdenum cleaner cells.
36. Cone thickener.
37. Disk filter.
38. Dryer.
39. Concentrate settling tank.
40. Concentrate thickener (40-foot diameter).
41. Disk filter.
42. Concentrate bin.

A. Mill balls (1.6 pounds per ton of ore).
B. Lime (3.5 pounds per ton of ore).
C. Water (291 g.p.m. each ball mill).
D. Flotation reagents: Pine oil, xanthates, etc.

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FIGURE 13. - Pit Conveyor and Concentrator Buildings.

Electrolytic Pilot Plant

Obviously, if the 0.4-percent copper in the overlying oxidized capping that must be mined and the additional oxidized 14.5 percent of the copper in the mill feed that is now lost could be recovered, the total recovery of copper from the Bagdad ore body could be increased 50 percent or more. Metallurgical testwork for applying a roasting, leaching, and electrowinning process to the Bagdad ore and pilot-plant design was done by Dorr-Oliver, Inc. Bagdad built the plant, and it was operated jointly by Bagdad and Dorr-Oliver in 1956.

This plant was designed to treat 5 tons of copper concentrate a day. The operation of this plant has been described.11/ The concentrate, containing 27 to 28 percent copper, 16 to 18 percent iron, and 27 percent sulfur, is fed to a FluoSolids reactor. Calcine from the reactor is quenched in spent electrolyte from the tankhouse, and the copper is dissolved. The pregnant solution is clarified and passes through electrolytic cells, where copper is precipitated on cathodes by an electric current. This process will produce refined copper with sulfuric acid as a byproduct.

11/ Mining World, Electrolytic Copper Production is Goal of Bagdad Pilot Plant Study: Vol. 19, No. 9, August 1957, pp. 50-53.

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The company plans to utilize this process and thus eliminate the expense of hauling concentrates to Hillside, as well as freight and custom-smelting charges. The byproduct acid will be used to leach the oxide dumps and thus increase the percent extraction of the copper in the ore body.

COSTS

The operating cost of some individual types of equipment is shown in dollar value. Stripping, mining, and milling costs are shown in percentages. The following tables (7 to 10) and lists show such costs as are available for publication.

TABLE 7. - Drilling costs

	Churn drill		Portadrill	
	Ore	Waste	Ore	Waste
General information:				
Shifts operated	460.5	348.5	29.0	146.0
Material drilled per shift, feet	53.73	83.48	148.21	329.36
Material drilled, do.	24,743.0	29,092.0	4,298.0	48,087.0
Cost per foot:				
Direct labor	$0.655	$0.422	$0.272	$0.123
Payroll taxes	.031	.020	.011	.005
Vacation and bonus	.025	.016	.006	.003
Provisions for bits and stems	.017	.011	.387	.174
Lubrication	.025	.016	.009	.004
Miscellaneous	.067	.043	.039	.018
Maintenance and repairs	.034	.196	.166	.074
Industrial insurance	.038	.024	.014	.006
Fuel	.057	.037	.053	.033
Total	.949	.784	.958	.440

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TABLE 8. - Loading costs

	Shovel capacity, yards								
	Diesel-powered shovels			Electric-powered shovels					
	2-1/2	3		3-1/2		4-1/2		6	8
	Ore	Ore	Waste	Ore	Waste	Ore	Waste	Waste	Waste
General information:									
Shifts operated...	7.75	57.25	68.0	92.0	5.0	32.5	149.25	199.75	161.75
Material loaded... .....tons	12,993.0	145,198.0	226,278.0	222,799.0	15,419.0	104,398.0	647,411.0	1,638,666.0	1,536,578.0
Material loaded per shift.....do.	1,677.0	2,536.0	3,328.0	2,422.0	3,084.0	3,212.0	4,338.0	8,204.0	9,500.0
Cost per ton:									
Labor.....	$0.0185	$0.0186	$0.0142	$0.0207	$0.0162	$0.0128	$0.0095	$0.0048	$0.0045
Payroll taxes.....	.0045	.0012	.0010	.0014	.0011	.0006	.0005	.0002	.0003
Vacation and bonus	-	-	-	-	-	.0002	.0005	.0001	.0002
Lubrication.....	.0095	.0026	.0020	.0016	.0013	.0015	.0011	.0006	.0006
Miscellaneous.....	.0355	.0060	.0046	.0078	.0061	.0041	.0031	.0017	.0025
Maintenance and repairs.....	.1435	.0464	.0354	.0642	.0504	.0475	.0362	.0083	.0203
Industrial insurance.....	.0056	.0015	.0012	.0017	.0014	.0008	.0006	.0003	.0004
Power.....	.0036	.0060	.0046	.0033	.0026	.0024	.0018	.0015	.0018
Total.....	.22	.08	.06	.10	.08	.07	.05	.02	.03

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TABLE 9. - Haulage costs

	End-dump trucks							Turnarockers		All haulage
	20-ton	22-ton (With torque converter)	22-ton (Without torque converter)	30-ton	50-ton	Diesel, 40-ton	Butane, 40-ton	40-ton	50-ton	
General Information:										
Material hauled....tons	147,228.0	3,100,105.0	535,933.0	5,346,676.0	756,670.0	3,538,162.0	59,172.0	25,414.0	60,573.0	13,569,933.0
Do.....hours	1,767.0	31,793.0	6,161.0	39,284.0	3,732.0	21,881.0	4,311.0	208.0	442.0	109,766.0
Do.....miles	7,701.9	180,317.1	27,293.4	261,576.6	20,203.1	112,724.3	21,833.2	1,012.9	1,913.0	635,863.6
Do.....units	5.0	10.0	4.0	10.0	1.0	6.0	2.0	1.0	1.0	
Cost per mile:										
Labor:										
Operating.....	$0.5352	$0.4121	$0.4958	$0.3465	$0.4637	$0.4897	$0.4947	$0.5183	$0.6775	$0.0485
Repair.....	.1340	.0347	.0677	.0238	.0668	.0368	.0140	.1622	.1402	.0340
Parts.....	.3931	.1273	.3028	.1247	.3144	.1543	.0603	.3843	.2628	.1459
Tires and tubes.....	.3383	.2970	.5343	.2161	.7460	.2180	.0326	1.3480	-	.2659
Oil and grease.....	.0370	.0242	.0375	.0219	.0431	.0318	.0183	.0175	.0364	.0257
Fuel.....	.2465	.1951	.2725	.2030	.2898	.2679	.3409	.2342	.3021	.2234
Total cost per mile	1.68	1.09	1.71	.94	1.92	1.20	.96	2.66	1.42	.74
Total cost per ton	.088	.063	.087	.046	.051	.038	.036	.106	.045	.051

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TABLE 10. - Comparison of truck and conveyor haulage costs

	Truck		
	30-ton	40-ton	Conveyor
Material hauled.....tons	1,548,290	932,560	1,351,513
Material hauled per hour.....do.	127.5	151.05	254
Costs per ton:			
Labor.....	$0.01964	$0.01781	$0.01394
Payroll tax.....	.0098	.00082	.00052
Vacation and bonus.....	.00039	.00076	-
Tires and tubes.....	.01794	.01065	1/.00017
Lubrication.....	.00197	.00196	.00001
Miscellaneous.....	.00479	.00347	.01228
Maintenance and repairs.....	.02655	.02688	.01002
Industrial insurance.....	.00122	.00102	.00080
Fuel.....	.01379	.01372	.00185
Total.....	.08727	.07729	.0396

1/ Material and supplies.

An analysis of stripping costs based upon 4,065,457 tons moved in 4 months of 1957 is given below.

	Percent of total cost		Percent of total cost
Direct labor.....	3.06	Loading.....	17.35
Other direct charges.....	.39	Haulage.....	45.78
Primary drilling.....	9.57	Dozers and graders.....	8.40
Secondary drilling.....	1.11	Miscellaneous.....	3.06
Blasting supplies.....	11.28	Total.....	100.00

Mining and milling costs for the same period were distributed as follows:

	Percent of total cost		Percent of total cost
Mine (ore and waste):		Concentrator:	
Operating:		Operating:	
Breaking ground.....	7.13	Primary crushing.....	1.55
Loading and hauling..	8.60	Primary conveyor.....	1.81
General mine expense.	2.32	Secondary crushing....	4.42
		Grinding.....	9.17
Total direct cost..	18.05	Flotation.....	7.96
		Filtering.....	1.04
Other:		Molybdenum section....	1.57
Diamond drilling.....	2.04	Tailings disposal.....	.89
Advance stripping....	47.19	Water supply.....	1.10
		General mill expense..	4.21
Total other costs..	49.23		
		Total concentrating cost.....	32.72
Total mining cost..	67.28		
		Grand total operating cost.....	100.00

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